Nearshore Processes

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LONG-TERM GOALS

The long-term goals are to understand the transformation of surface gravity waves propagating across the nearshore to the beach, the corresponding wave-driven circulation, and the associated evolution of surfzone morphology.

OBJECTIVES

The FY98 objectives were to obtain field observations on a natural beach to develop and test hypotheses about the

- transformation of surface waves across the nearshore and surf zone

- generation and spatial variation of wave-driven setup and near-bottom circulation

- evolution of the nearshore bathymetry in response to waves and circulation

An additional objective is to provide data supporting other SandyDuck studies of wave transformation, circulation, sediment transport, and acoustic properties.

APPROACH

Our approach is to test hypotheses by comparing model predictions with field observations. Waves, currents, and bathymetry were observed on a natural beach during the SandyDuck field experiment on the North Carolina coast. Pressure gages, current meters, and sonar altimeters were deployed on a grid extending 370 m from near the shoreline to about 5 m water depth and spanning 200 m along the coast (Figure 1). The two-dimensional array allows quantitative investigations of sea and swell, edge waves, shear waves, nearshore circulation, and changing morphology.

In collaboration with T. Herbers, Boussinesq models for the evolution of directionally spread breaking and nonbreaking waves are being developed and tested by comparison with the array observations. Breaking complicates wave evolution, but the nonlinear triad interactions included in Boussinesq models appear to be important throughout the shoaling region and the surf zone. The SandyDuck observations are also being used to test hypotheses about wave-breaking induced setup and the corresponding offshore directed undertow (with Raubenheimer), mean circulation and bottom stress (with student Falk Feddersen), shear waves (with student Jim Noyes), and the evolution of the sand bar-scale

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**
4. TITLE AND SUBTITLE **Nearshore Processes**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Electrical Engineering and Computer Science,Pullman,WA,99164-2752**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **See also ADM002252.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

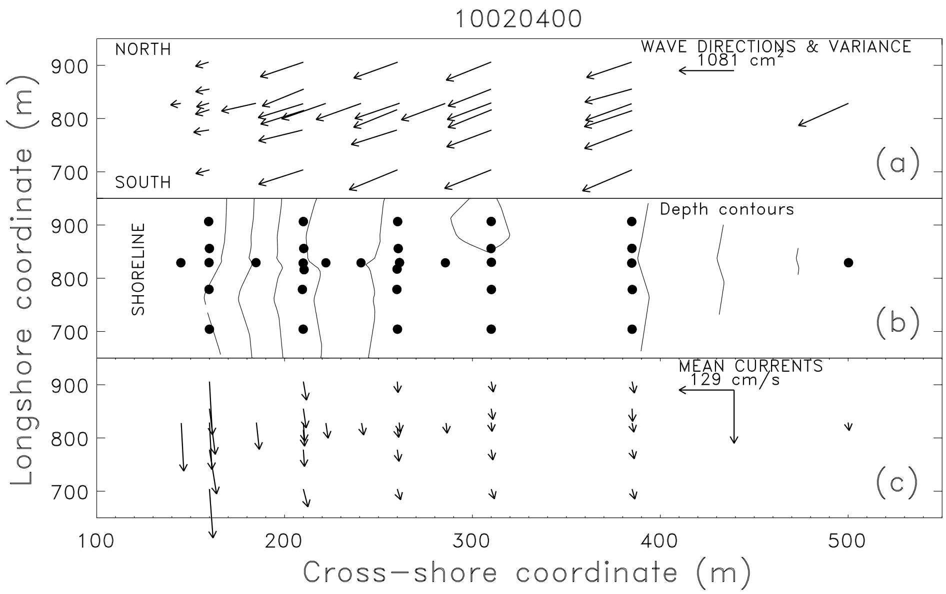

Figure 1: Summary of observations obtained during a 3 hr-period (0400-0700 hrs, 2 Oct 1997). Incident waves with significant height about 1.2 m began breaking at cross-shore coordinate 230 m. Each panel shows a plan view of the instrumented region with north toward the top and the shoreline to the left. (a) Wave propagation direction (indicated by the arrow direction) and wave variance (proportional to the arrow length) estimated with data from a biaxial current meter and pressure sensor located at the base of each arrow. (b) Depth contours (from 1 to 5 m, in 50 cm intervals) based on sonar altimeters (filled circles). (c) Mean (3-hr average) currents (direction and magnitude are indicated by the arrow direction and length, respectively). The longest vector corresponds to about 129 cm/s.

morphology.

WORK COMPLETED

Observations of waves, currents, and the bathymetry were acquired nearly continuously for about 4 months (Aug - Nov 1997). Preliminary data processing is complete, and maps of nearshore wave heights and directions, bathymetry, mean flows, and setup every 3 hours for the entire experiment have been produced.

One-dimensional Boussinesq shoaling wave models have been compared with observations made on the cross-shore transect of the Duck94 pilot experiment (Chen et al. 1997, Norheim et al. 1998). The directional spread of energy was shown to increase as waves broke over a sand bar, in contrast to the directional narrowing predicted by linear refraction theory (Herbers et al. in press). Comparison of the bottom drag of the longshore current with the wave radiation stresses shows that currents within the surf zone are primarily wave-driven and that the alongshore bottom stress is represented well by a quadratic bottom drag law (Fedderson et al. 1998). Seawards of the surf zone, mean alongshore currents are driven by wind, density gradients, and large-scale alongshore pressure gradients. Wave-driven setup is an important component in the cross-shore momentum balance immediately seawards of the surf zone, and the balance is not geostrophic (Lentz et al. submitted). A morphological evolution model was shown to predict the offshore sandbar migration observed in Duck94 (Gallagher et al.

1998a). The alignment and migration direction of megaripples, bottom features with amplitudes of about 25 cm and wavelengths of a few m, were shown to be determined by both mean and wave flows such that the gross sediment transport normal to the bedform is maximized (Gallagher et al. 1998b).

RESULTS

Inhomogeneities in the nearshore bathymetry (eg, sand bars and rip channels) result in gradients of wave heights that cause complex nearshore circulation and morphological evolution. However, even when the bathymetry is relatively smooth locally, alongshore gradients in wave properties can be caused by offshore or upcoast inhomogeneities. The pilings and bathymetry associated with the large pier 200 m south of our SandyDuck array produce alongshore gradients in wave height and direction when waves approach the beach from the south (Figure 2a), even though the bathymetry within the array was homogeneous (Figure 1b). In contrast, waves approaching from the north are not affected by the pier, and thus do not have strong alongshore gradients in wave height (Figure 2b). The effects of the pilings and the relatively deeper water under the pier are being investigated by comparing the observations with model predictions (with O'Reilly, Herbers, Raubenheimer).

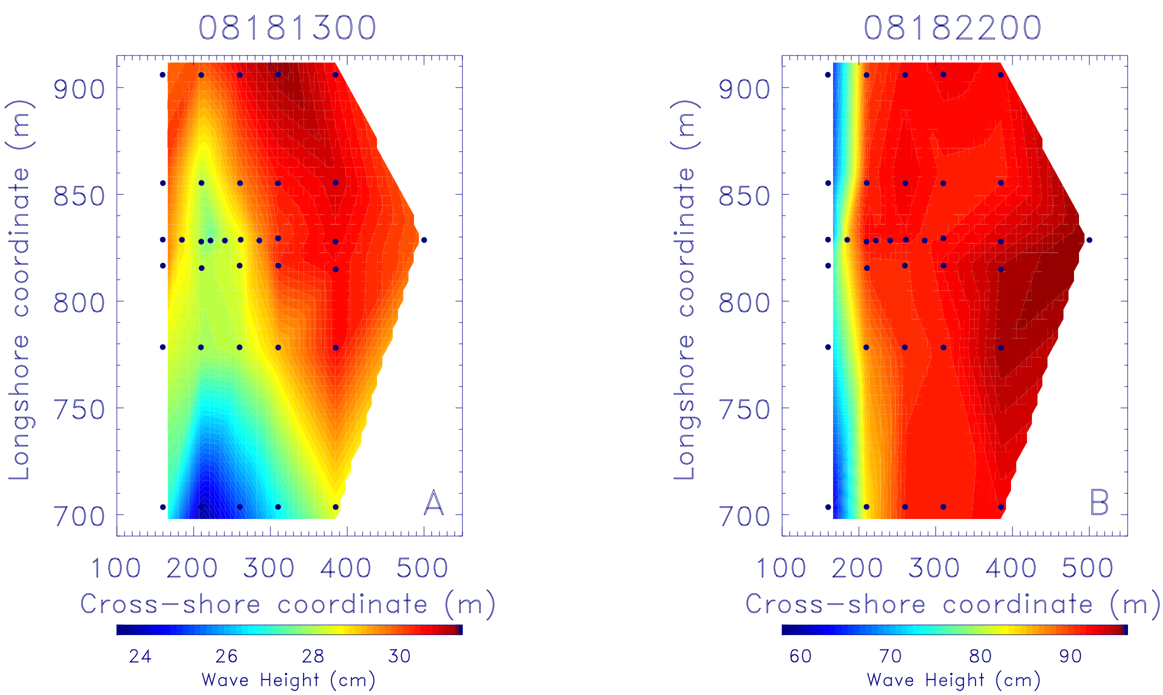

Figure 2: Contours of significant wave height observed with our SandyDuck array (filled circles). (a) The array is partially sheltered from low amplitude waves arriving from the south and propagating past a pier located at longshore coordinate 500 m, 200 m south of the array. Wave heights are lowest near the pier. (b) Larger amplitude waves approached the beach from the north, and propagate to the array unobstructed by the pier. Much of the array is within the surf zone and wave height gradients are largest in the cross-shore direction.

During SandyDuck, moderately energetic waves (1.2 m offshore significant wave height) obliquely incident on the shoreline (Figure 1a) drove strong (1.3 m/s) mean longshore currents that were confined to the surf zone (Figure 1c). Previous results suggest these horizontally sheared alongshore currents often are unstable (Oltman-Shay et al. 1989). The growing instabilities, called shear waves, are most energetic in the period range of 1-10 minutes (the infragravity frequency band in Figure 3). The alongshore wavelengths of shear waves are an order of magnitude shorter than wavelengths of surface gravity waves of the same frequency. Student Jim Noyes is using each of the 5 alongshore arrays (Figure 1) to determine the distribution of infragravity energy as a function of wavelength and frequency, yielding the first estimates of the cross-shore variation of shear wave energy. Near the shoreline, where the mean alongshore current is strong, the total infragravity energy (shear plus gravity waves) is maximum (not shown), with approximately 70% contributed by shear waves (Figure 4a). Farther offshore, the total infragravity energy is less and only 30% is contributed by shear waves. Shear wave energy is 100 times higher near the shoreline than 350 m seaward (Figure 4b). These observations are being compared with numerical simulations of the nonlinear shallow water equations (Allen et al. 1996).

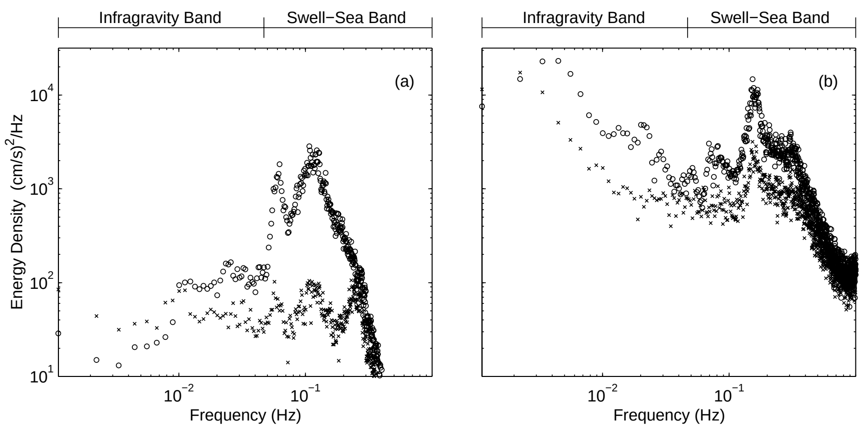

Figure 3: Spectra of cross-shore (o) and longshore (x) velocity near the shoreline in cases where the infragravity frequency band is dominated by (a) gravity waves (the mean longshore current V is weak, 3 Sep 1997, not shown) and (b) shear waves (V is strong, 2 Oct 1997 at 0400, Figure 1).

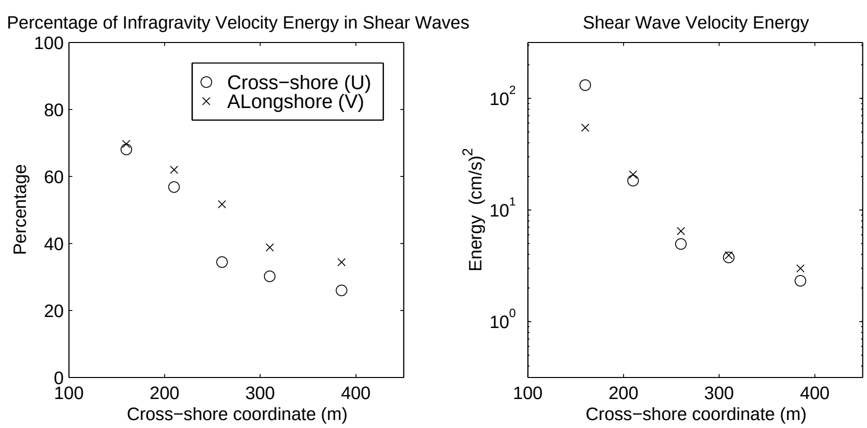

Figure 4: Cross-shore variation of (left) percentage of infragravity energy contributed by shear waves and (right) shear wave energy (2 Oct 1997 at 0400).

IMPACT/APPLICATIONS

The SandyDuck observations will be used to verify and improve wave, circulation, and morphological change models of interest to oceanographers and engineers. In addition, the spatially and temporally extensive observations provide the opportunity to discover new phenomena not included in present models.

TRANSITIONS

The sonar altimeters developed under this program are being utilized by other scientists, including altimeters mounted on the CRAB (Thornton, Gallagher), on a movable instrument sled (Thornton, Stanton), on the FRF's Sensor Insertion System (Miller, Resio), and as part of the European COAST3D experiments (on the WESP (Gallagher) and on a fixed platform (Miles)).

RELATED PROJECTS

The observations of nearshore waves, currents, and bathymetry compliment collaborative (with Herbers and O'Reilly) investigations of wave propagation across the continental shelf.

We also are collaborating with other SandyDuck investigators, including using our measurements of waves, currents, and bathymetry in studies of bottom roughness (hydraulic drag) (Thornton, Drake), wave breaking (Lippmann), the vertical distribution of currents (Thornton, Hathaway), circulation (J. Smith, Trizna, Kirby), the determination of bathymetry from wave data (P. Smith, Holland), acoustical properties (Hay, Heitmeyer), wave-breaking induced bubbles (Su), nearshore bedforms (Hay, Thornton, Gallagher), sediment transport (Miller, Resio), video estimation of surfzone currents (Holman, Bruno, Freilich), and swash processes (Holland, Sallanger).

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